Hume Lake Dam
Sequoia National Forest
Fresno County Hume
California

HAER No. CA-16

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PHOTOGRAPHS

HISTORICAL AND DESCRIPTIVE DATA

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Historic American Engineering Record
National Park Service, Western Region
Department of the Interior
San Francisco, California 94102

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HISTORIC AMERICAN ENGINEERING RECORD

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Richard K. Frear, Photographer — August, 1982

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Historic American Engineering Record

Hume Lake Dam

HAER CA-16

Location: On Ten Mile Creek in the Sequoia National Forest, Hume
Fresno County, California

Date: 1908-09

Designed by: John S. Eastwood

Owner: Originally built by the Hume-Bennett Lumber Co.; sold to its present owner, the U. S. Forest Service, in 1935.

Significance: Hume Lake Dam was the world's first reinforced a concrete multiple arch dam. Built to impound reservoir for the Hume-Bennett Lumber Company, today it is the only major surviving structure representing the Kings River Basin's redwood logging industry. It is significant for its innovative use of reinforced concrete and for its association with an important regional industry.

Historian: Donald C. Jackson, HAER Engineer/Historian, 1983

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INTRODUCTION

Built in 1908-09, the Hume Lake Dam was the world's first reinforced concrete multiple arch dam. It rises 61 feet from its bedrock foundation on Ten Mile Creek in Sequoia National Forest, stretches 677 feet, and incorporates 12 arches with spans of 50 feet. The dam was designed for the Hume-Bennett Lumber Company by John S. Eastwood, a Fresno-based engineer with experience in the development of hydroelectric power. Following the successful completion of this multiple arch structure, Eastwood went on to design 16 other dams built applying the same principals prior to his death in 1924.

Construction of Hume Lake Dam began in the summer of 1908, and the reservoir was first filled in 1909. The Hume-Bennett Lumber Company commissioned the project to provide a storage pond for Giant Sequoia redwood and other timber awaiting milling in the Hume Lake sawmill. In addition, the dam provided a source of water for the 67-mile long flume that carried the cut timber out of the Sierra mountains. The lumber industry declined through the 1920s and, in 1935, the dam came under the control of the U. S. Forest Service. Today it serves exclusively recreational purposes.

The significance of Hume Lake Dam goes beyond its association with the redwood logging industry, as it is of major importance in the evolution of reinforced concrete technology and the history of hydraulic engineering. The success of this dam demonstrated the feasibility of reinforced concrete buttressed dams in regions of extreme climates and provided proof of the economic advantages of multiple arch construction. By designing a dam in which the upstream face consists of a series of inclined arches that, in turn, are supported by buttresses founded directly on bedrock, Eastwood devised a materially conservant means of building water impounding structures. He minimized the amount of concrete required to hold back a given height of water and, in so doing, also minimized the cost of transporting cement, a major consideration when working in remote mountain locations.

After completion of Hume Lake Dam, other engineers emulated Eastwood's work and by 1930 over 50 multiple arch dams were in use throughout the world.[1] Beginning in the 1930s, however, the technology of dam construction underwent radical changes as earth-moving and material conveyance machinery attained far greater capacities than previously possible. With these developments, the economic advantages of the multiple-arch dam were tempered, and it did not sustain the popularity it achieved between 1910 and 1930. Even so, multiple arch dams continued to be built through the 1960s and they have proven to be a particularly safe and reliable type of water storage structure.[2] In the United States, there has never been a failure of a multiple arch dam that resulted in loss of life or property.

This report provides a history of the Hume Lake Dam with emphasis on Eastwood's early career and the engineering theory behind multiple arch dam design. Though the structure played a significant role in the Hume-Bennett logging operation, it is not feasible for this report to incorporate any new analysis of redwood logging history. Readers who wish to learn more about this should consult Hank Johnston's They Felled the Redwoods (Los Angeles: Trans Anglo Press, 1966) and Marley Brown and Michael Elling's report, An Historical Overview of Redwood Logging Resources within the Hume Lake Ranger District (U. S. Forest Service Contract No. 40-9A23-0-1449, May 1981). The former is a well-illustrated, extremely readable book that, despite lacking documentary footnotes, is an excellent resource for historians interested in Sierra lumber operations. The latter publication was prepared under contract with the Forest Service as an aid in evaluating the historic significance of resources in the Hume Lake area that may be affected by future construction and/or logging projects. Brown and Elling provide especially good background information on the natural and cultural history of the entire Sequoia National Forest area.

History of the Redwood Logging Industry Preceding Construction of Hume Lake Dam

Among the most remarkable features of the Southern Sierra Nevada Mountains are the huge Giant Sequoia redwood trees. Acknowledged by naturalists to be the largest living organisms on earth, at one time they covered extensive areas at altitudes between 5000 and 7000 feet.[3] Giant Sequoias were first logged by white settlers during the 1860s and 1870s, with much of this activity focusing on the redwood groves east of Fresno and between the Kings River to the north and the Kaweah River to the south. Beginning in the 1880s, larger and more mechanized logging operations developed in the region and, in terms of production, quickly began to supercede the small-scale mills that preceded them.[4] The most important of these operations were run by Hiram C. Smith and Austin D. Moore and their corporate descendants.

In 1890 Smith and Moore's Kings River Lumber Company completed construction of a flume to transport cut timber from its sawmill at Millwood to its lumber yard near the Southern Pacific tracks in the town of Sanger some 60 miles away.[5] This flume eliminated the need for timber to be hauled slowly and arduously out of the mountains by animal power. It allowed large amounts of lumber to be transported quickly and opened the way for massive exploitation of the huge redwood grove in the Converse Basin. During the 1890s Smith and Moore cut down thousands of Giant Sequoia in this basin and their wasteful techniques served as a catalyst for naturalist John Muir to press for federal protection of other surviving redwood groves. Ironically, in spite of the flume and the use of mechanized logging techniques, the Smith and Moore operation never achieved financial success and by the early 20th century had irrevocably succumbed to bankruptcy. By this time their Kings River Lumber Company had been reorganized as the Sanger Lumber Company.

Concurrent with the Sanger Lumber Company's financial collapse, a Michigan-based logging enterprise owned by Thomas Hume of Muskegan, Michigan, was actively expanding its timber holdings throughout the United States.[7] Knowing of Hume's interest in buying timber land, a Western lumberman named Ira Bennett brought to his attention the former Smith and Moore holdings east of Fresno and described them as comprising an excellent investment opportunity. Bennett's salesmanship proved convincing and, in late 1905, the newly-formed Hume-Bennett Lumber Company bought the former Smith and Moore holdings with the intent of recommencing large-scale lumbering activities in the region. Soon after completing the purchase, however, the company realized that the Converse Basin area had already been logged so extensively that, in order to turn a profit, future operations would need to extend much deeper into the Kings River watershed. At this time the company chose to abandon the huge sawmill at Millwood and construct a new mill higher in the mountains.[8]

Smith and Moore's original flume from Millwood followed Mill Flat Creek as far as its confluence with the Kings River and then paralleled the latter water course until terminating in Sanger. In expanding their operation, the Hume-Bennett Company went upstream along the Kings River until meeting Ten Mile Creek, the next major tributary entering from the South. It was along this creek that the company planned a sawmill designed to connect with the original Millwood flume via a new 17-mile extension. In planning for the new mill, the Hume-Bennett Company determined that it would be most advantageous to locate it adjacent to a large reservoir for two reasons. First, by building the mill next to a large logging pond it would be easy to store and handle logs prior to their being cut. Second, the reservoir would insure that the flume always held sufficient water to carry the lumber cut at the mill, regardless of temporary droughts.[9]

During the summer of 1907, the company began actively working on the design of its new facility and dam. However, it had difficulty obtaining the services of an engineer to design the dam that would impound the future Hume Lake. At least two engineers declined to take charge of the dam project before John S. Eastwood proposed to take on the work. But in making this proposal, Eastwood stipulated that he be allowed to build a new type of reinforced concrete dam at the site. The company was intrigued by the financial savings that Eastwood claimed his "multiple arched dam" would allow when compared with a rock-fill dam of similar size, but they moved cautiously in approving a new and radical type of design. Consideration of Eastwood's proposed design began in the fall of 1907, but it was not until the spring of 1908 that the company decided to fund construction of the world's first reinforced concrete multiple arch dam.[10]

John S. Eastwood's Early Career

Born in Minnesota in 1857, John Eastwood grew up in his native state and studied civil engineering at the University of Minnesota during the late 1870s.[11] In 1880 he left the Midwest to work on railroad construction projects in the Pacific Northwest and, from that time on, his professional life focused exclusively on the Pacific Coast region. In 1883 he left the Pacific Northwest and headed for California's Central Valley. During his three years of railroad work, his surveying and construction skills developed to the point where he considered himself qualified to set up his own office as a "Surveyor-Civil Engineer." At this time Fresno was a recently established railroad town 20 miles south of the San Joaquin River and the rapidly growing city appeared to offer numerous opportunities for someone possessing practical engineering skills. In 1884 Eastwood opened a downtown office in Fresno with the hope of soliciting work in the region.[12]

Eastwood's interest was not confined to the valley floor around Fresno and he soon visited the redwood groves along the Kings River watershed.[13] In 1885 he became Fresno's first city engineer, but soon chafed under the relatively sedentary life of a bureaucratic engineer and began directing his energy towards projects that extended beyond municipal concerns. Eastwood returned to the redwood logging region in 1887 and led the surveying team that laid out the route of Smith and Moore's 60-mile, Millwood-to-Sanger lumber flume.[14] Though Smith and Moore's chief engineer received public credit for construction of this flume, it is almost certain that Eastwood made a major contribution to its successful erection.[15] With this project, Eastwood first became involved with an hydraulic engineering project of major scope while aiding the development of the redwood logging industry. Almost twenty years later, he would again participate in the region's logging industry, but this time as designer of a new type of reinforced concrete dam.

In the early 1890s, Eastwood worked on irrigation projects around Fresno but, after the Panic of 1893 brought these activities into financial difficulty, his interest soon focused on a new technology promising great benefit for the Fresno region: hydroelectric power.[16] Beginning with construction of America's first 3-phase alternating current power system in Redlands, California, in 1893, the West Coast led the way in the development of long distance electric power systems throughout the last decade of the 19th century.[17] As chief engineer of the San Joaquin Electric Company, Eastwood played a major role in the growth of hydroelectric power in California, because of both his pioneering work in hydroelectric design and his active participation in the newly-formed Pacific Coast Electric Transmission Association.

First organized in April 1895, the San Joaquin Electric Company (SJEC) began transmission to Fresno over an 11,000 volt, 37-mile-long power line in April 1896. Carved out of the rugged and remote terrain along the North Fork of the San Joaquin River, the SJEC plant operated under a head of 1,410 feet, by far the highest in the world at the time. Because of the great expense involved in constructing the system's diversion ditches, steel penstock, masonry powerhouse and transmission line, the SJEC lacked the financial capability of building a storage dam in the mountains to insure that the system would always have an adequate water supply. As a result, Eastwood was forced to rely on an undammed, natural supply of water to drive the turbines and generators. It was this inability to impound and store runoff that led to the demise of the SJEC in 1899 after a long drought dried up the North Fork of the San Joaquin River and brought the company's power production to a standstill.[18]

Though drought led to the SJEC's financial failure, in all other respects it was a great technological success and Eastwood's interest in hydroelectric power development continued unabated. However, he now appreciated the critical importance of constructing storage dams as an integral part of Western hydroelectric power systems. Shortly after the turn of the century, Estwood became involved with Henry Huntington's Pacific Light and Power Company in designing a huge hydroelectric system on the main fork of the San Joaquin River.[19] Known today as Southern California Edison Company's Big Creek Project, this system included a series of hydroelectric plants operating under heads of 2000 feet and more, several miles of tunnels driven through hard rock, and several storage dams to regulate the flow of water throughout the year. Because of his experiences with the San Joaquin Electric Company, Eastwood was prompted to consider how the cost of building storage dams high in the mountains could be reduced. The dam sites associated with Big Creek were so isolated that material transportation costs became a major factor in the expense of building structures at these locations. Eastwood determined that by minimizing the amount of concrete used in the dams, it would be possible to reduce transportation costs substantially and make the entire project more economically feasible. It was in this context that Eastwood conceived of designing a new type of inexpensive dam.

Although Big Creek was largely designed prior to 1905, financial difficulties delayed its construction for several years. During this time Eastwood developed the idea of a reinforced concrete multiple arch dam, a concept previously discussed by other engineers, but never actually implemented.[20] When Eastwood began negotiations with the Hume-Bennett Lumber Company in the fall of 1907, his intent was to erect a multiple arch dam that would demonstrate to others the practicality of building this type of structure. Once one multiple arch dam was in operation, then the viability of using others of this type on the Big Creek project would become apparent. Hume Lake Dam was to be a stepping-stone that would bring him closer to constructing the Big Creek project. In 1910 he continued development of his multiple arch concept with construction of the New Big Bear Valley Dam near San Bernardino but, at the end of the year, his hopes for the Big Creek project were crushed. At that time, the Pacific Light and Power Corporation (a corporation formed by Huntington to control the assets of the Pacific Light and Power Company) dismissed him as chief engineer for Big Creek and construction of the project became the responsibility of a large East Coast engineering firm.[21] As a result, he began actively pursuing a career devoted to the design of multiple arch dams. Although Eastwood originally intended his pioneering work at Hume Lake to be an adjunct to hydroelectric power system design, it soon became a "jumping-off point" for his total dedication to problems associated with the construction of multiple arch dams.

Theory of Multiple Arch Dam Design

The function of a dam is to hold back, or impound, a volume of water so that it can be put to use at a later time. This use of water may be related to logging, irrigation, hydroelectric power production, domestic water supply, or even recreational activities; but in all cases the function of the dam remains the same. Though there are many different types of dams employing a variety of materials, all water impoundment structures must include two basic features:

1) an impervious upstream surface that the impounded water cannot penetrate, and

2) a structural system that supports the impervious surface and is safely keyed into the site's foundation.

Any dam that successfully incorporates these two features into its design should function satisfactorily.

In a multiple arch dam, the reinforced concrete arches form the structure's "impervious upstream face," and the reinforced concrete buttresses provide the support for this surface. When the reservoir behind the dam is filled with water, the hydrostatic pressure is exerted directly on the upstream face and, through "arch" action, the water pressure is concentrated on the buttresses. The hydrostatic pressure is then carried through the buttresses to the foundations. Because the spans of all the arches are equal, their respective sideward thrusts due to water loadings cancel one another and the only forces the buttresses must sustain are those perpendicular to their upstream faces.

In designing his reinforced concrete dams, Eastwood was concerned that they not be subjected to tensile forces because tensile forces work to pull apart, or separate, the members they are acting on.[22] Within a dam, the presence of tensile forces can be disastrous, as they can act cumulatively and, if their magnitude becomes too great, destroy the structure. It was for this reason that Eastwood built the upstream face of the Hume Lake Dam as a series of arches. Within the arches, all stresses from water loadings are compressive and this eliminates the possibilty of dangerous "tensile cracks" appearing on the upstream face. To insure that the buttresses also are not subject to tensile forces that will work to overturn them, Eastwood inclined the arches and the buttresses upstream at an angle of 32 degrees. By inclining the arches and buttresses, he was able to utilize the weight of water that pushes directly down on the dam as an aid in stabilizing the structure. Instead of relying solely on the weight of the dam's concrete to hold back the water, as is the case of a vertically-faced gravity dam, part of the stored water itself is used to keep the structure stable. The technique of angling a dam's upstream face was not invented by Eastwood but rather had been used since the 16th century.[23] Though the Hume Lake Dam represented a sophisticated use of this technological concept, it was not an unprecedented application.

Once the basic form of the multiple arch dam had been determined, Eastwood used an equation known as "Rankine's Ring Formula" to proportion the actual dimensions of the structure. This formula allowed the thickness (T) of the arches to be calculated in relation to: 1) the hydrostatic pressure (P) placed on them, 2) the radius (R) of the arch, and 3) the maximum allowable stress (Q) in the concrete. This formula (usually expressed as $T=PR/Q$) provided Eastwood with a means of calculating how thick the arches should be at any given elevation. He selected the allowable stress Q in the arches concrete to be 187.5 pounds per square inch (psi) and from this determined the rest of the dam's dimensions.[24] Once the size (and hence weight) of the arches became known, this data, in conjunction with the known hydrostatic pressures for a given depth of water, allowed the buttresses to be designed such that they also would be subject to a maximum allowable stress of 187.5 psi.

As a result of his efforts to construct the dam so that all parts of it were subject to the same maximum allowable stress, Eastwood made sure that no part of the structure contained excess material that did not contribute to its safety. Just as with a chain, a dam is no safer than its "weakest" link. By making all parts equally strong, he prevented any part of the dam from containing too much, or too little, concrete.

The hydrostatic pressure exerted by the stored water acts perpendicularly to the axis of a multiple arch dam and cannot work to "topple" the buttresses to either their left or right. However, there is the possibility that earthquakes can create "cross-stream" forces parallel to the dam's axis that may work to topple the buttresses sideways. To counteract this, Eastwood designed the downstream side of the Hume Lake Dam's buttresses with a "tee-section" that greatly increases their resistance to cross-stream loadings. It is well known that a creased piece of paper can stand on its end much more easily than an uncreased piece of paper. This same basic principle explains why the buttresses' "tee-sections" add to their lateral stability. In conjunction with this, it is worth noting that the dam's inclined upstream face also helps the structure resist earthquake forces by having water push directly down on the buttresses. This vertical pressure on the buttresses reduces their susceptibility to lateral "buckling" that might right from seismic forces.

Because the arches and buttresses of a multiple arch dam are only subject to compressive stresses under normal hydrostatic loadings, it is important to explain why Eastwood placed over 7 miles of steel cable within the Hume Lake Dam as reinforcement. The purpose of this steel was to strengthen the dam against temperature stresses that might develop during periods of cold weather. As the temperature of the dam drops, there is a natural tendency for it to shrink and, without some amount of steel in the concrete to resist this shrinkage, cracks can appear in the structure. As with other types of "tensile cracks," those resulting from shrinkage can precipitate failure of a dam and should be avoided. Such "tensile cracks" would appear vertically along the surface of the arches and should not be confused with small horizontal cracks running across the arches that were formed at the time of the dam's construction. These horizontal cracks are often called "lift lines" because they represent the different "lifts," or batches, of concrete that were poured during construction. Though these lift lines can allow small amounts of water to seep through the dam, they are by no means as dangerous or destructive as vertical cracks resulting from tensile stresses.

In sum, the theory of multiple arch dam design is based on the objective of creating a structure in which all parts are placed solely in compression. By then proportioning the dam so that all parts are under an identical stress, the structure can be designed to use a minimum amount of concrete. In this way, a safe and economical design is produced.

Construction and Operation

Eastwood began surveying for the placement of the dam in June 1908 and, by the end of the month, blasting and other foundation work was underway.[25] Clearing of the reservoir site had taken place during the late spring and, by the time work on the dam commenced, Long Meadow was largely devoid of standing timber.[26] The hard granite foundation at the dam site is extremely close to the surface, eliminating the need for extensive excavation work. However, Eastwood directed that foundation trenches be blasted out along the entire length of the dam to insure tight "keying" of structure into granite. These trenches were described as being similar to "rifle pits" and were excavated largely by hand.[27]

During most of the summer, activity at the dam site consisted of preparatory work such as blasting, quarrying and crushing rock, cutting and transporting wood and erecting the construction plant. At this time, Eastwood also "layed out" the design of the construction plant to be used in erecting the dam. In undertaking such an endeavor, Eastwood could not rely upon any previous experience as a reinforced concrete contractor. Instead, he was forced to draw upon basic techniques developed during construction of the San Joaquin Electric Company's system when he faced many new and unforeseen problems. Beginning with Ernest Ransome's pioneering work in the late 19th century and continuing with the work of engineers such as John Leonard in the early 20th century, reinforced concrete had achieved some standing in the world of California construction technology by the time work started on the Hume Lake Dam.[28] Nevertheless, this earlier work in reinforced concrete construction largely concerned bridges and buildings and would have been of only limited value to Eastwood in planning the erection of his dam.

Beyond the construction of wooden forms designed to hold wet concrete as it hardened (or "set"), the most important part of the erection process concerned the transportation of materials around the dam site.[29] The first major structure Eastwood built was a wooden trestle extending the entire length of the proposed dam at a height slightly greater than the dam was to reach. Running along the top of this trestle was a tramway capable of carrying materials, such as wood or concrete, to any part of the dam. To provide for the lifting of heavy materials, Eastwood erected a hoist in the middle of the construction area. Its major function was to lift buckets of wet concrete from the concrete mixer (located slightly upstream from the dam) and carry them to tramcars located on the main trestle. In addition to the hoist and main trestle, there was also a smaller trestle used to deliver rock taken from the quarry near the western end of the dam to a storage area adjacent to the rock crusher. Granite carried on this smaller trestle was dropped approximately fifty feet to the storage area below in order to help break it up before placement in the crusher. The resulting aggregate was then mixed with sand and cement in the mixer to produce concrete.

Before the concrete could be put in place, it was necessary to construct wooden forms for the buttresses and arches. These forms consisted of 1/2"x6" boards supported by 2"x4" studding. In order to insure that the arch forms held the proper circular shape, Eastwood stated that:

> "The studs were held to their proper place by 'liners,' or segments of a circle, cut to the template of a pattern and assembled in place in sections, the studs being toenailed to them at the bottom, and thru-nailed at the top, set flush with the inside and outside of the liner, as the case may be, for inside or outside studs."[30]

In large part, the construction of the formwork for the 13 buttresses preceded erection of the arch forms, as it was Eastwood's desire to build the buttresses well in advance of the arches. Because the buttresses were to support the arches, it was important that they be given sufficient time to harden before they were required to bear the weight of the arches. However, once concrete began to be poured in mid-August, the first part of the dam to be constructed was the three shallow arches and four buttresses located at the west end of the structure. Presumably, Eastwood wished to be sure that his technique for joining the buttresses and arches into a monolithic unit was satisfactory before commiting himself to it for the entire dam. His scheme evidently proved practical, because all the rest of the buttresses were completed before any work started on the remaining arches.

Work on the dam began in late June 1908 and continued through November with a construction crew that averaged approximately 40 men. It appears these men were previously active in the redwood logging industry and there is no evidence that any workers on the dam were brought in from outside the immediate area. Common laborers received $2.25-$2.50 per day; skilled laborers received $3.00 per day; and carpenters received $3.50 per day. Because of their role in building the formwork to the exact configuration required by Eastwood's design, it was logical that the carpenters earn a higher wage than the rest of the work crew. In total, Eastwood reported that 114 working days were required to construct the dam.[31]

To insure that minor freshets in the Ten Mile Creek watershed did not disrupt construction, a flume was built to channelize the creek through the dam site. A special opening was left in the deepest arch to provide passage for the flume during completion of the dam. Rather than immediately close up the flume opening in November 1908, Eastwood let the structure stand empty until June 1909 in order to test its ability to withstand tensile stresses induced by severe temperature. Following the successful completion of this test, the opening for the flume was closed and the reservoir began to fill up. During the summer of 1909, work continued on the rest of the Hume-Bennett Lumber Company's facility at

Hume Lake. In September, water first began to flow from the reservoir into the newly-built flume designed to carry lumber to the old Millwood flume and thence to the lumberyards in Sanger.[32] With this, the Hume Lake Dam was ready to begin full operation.

As previously stated, the Hume Lake reservoir served two purposes: 1) to provide a storage pond for timber awaiting cutting in the sawmill; and 2) to provide water for the flume. Huge trees (both Giant Sequoia and pine) were brought to the lake by logging trains and then dumped into the water. Here, they floated on the lake until hauled into the sawmill for cutting. The timber was then dried in kilns before being placed in the flume for transportation downstream. Water for the flume was released from the dam through two 12" outlet valves set in the arches. In order to provide additional means of release from the reservoir in times of heavy flooding, Eastwood also built 12 5'x8' spillway openings into four of the dam's arches and placed a 24" valve at the bottom of the deepest arch. With these it was possible to completely regulate the level of the reservoir to best serve the company's needs.[33]

During the first 8 years of the dam's existence, it operated as part of an extremely active, though not always profitable, logging operation. However, in November 1917 a fire destroyed the main sawmill at Hume Lake and, after that, logging in the region began a rapid decline.[34] The dam remained in relatively good condition through the 1920s and, when the U. S. Forest Service bought it (along with many other holdings) from the Hume family in 1935, serious consideration was given to using it as part of a hydroelectric generating facility.[35] By this time, however, the recreational uses of the dam were becoming apparent and it soon began to provide campers and tourists with amenities far different from its original industrial purposes. For a brief period in the 1950s, the structure came under the control of the State of California and at that time its upstream face was coated with a 6" layer of concrete to help reduce leakage. This work included filling in the original spillways in with concrete, the only major alteration of the reinforced concrete structure during its entire history.[36] Since that time, the Hume Lake Dam has functioned adequately, but its condition is monitored continuously by the U. S. Forest Service to insure the structure's stability and soundness.

EPILOGUE

After completing the Hume Lake Dam, Eastwood went on to build 16 more multiple arch dams in California, Arizona, Idaho, Utah, and British Columbia, prior to his death in August 1924.[36] Following dismissal from the Big Creek project in 1910, his subsequent work did not focus exclusively on hydroelectric projects but related to a wide variety of water uses. These included dams to hold back debris for mining companies, dams to store water for irrigation districts, and dams to impound water for municipal uses including flood control. Interestingly, after finishing the Hume Lake Dam, Eastwood never again built a dam for a logging company nor did he build any more dams in the Fresno region of the Sierra Nevada. After spending the first part of his engineering career investigating the hydraulic potential of the San Joaquin and Kings Rivers' watersheds, he moved on to designing dams for clients throughout the rest of California and the mountainous West. Though the specific features of Eastwood's multiple arch dams evolved continually throughout the last 16 years of his life, the basic principals used in designing the Hume Lake Dam were always adhered to in his later structures. His desire to minimize the amount of concrete required for a dam never wavered, and all of his structures incorporated as series of arches supported on buttresses.

The operational life of Hume Lake Dam as a component of the redwood logging industry lasted for little more than a decade. By the time of the Great Depression of the 1930s, logging in the Hume Lake region had come to a halt and, with the sale of the dam to the U. S. Forest Service in 1935, the structure no longer played any role in logging activities. Since that time it has provided superb public recreational opportunities and is a great attraction for tourists and campers visiting the Sequoia and Kings Canyon National Parks and the Sequoia National Forest.

Today, the Hume Lake Dam is the last surviving major structure associated with the region's redwood logging industry. Born out of a company's utilitarian desire to expand operations and an engineer's vision of the potential that reinforced concrete offered to the field of hydraulic design, the dam stands as a powerful work of engineering attesting to the construction skills of a bygone generation. The bold massing of the arches and buttresses, unencumbered by decoration and frill, imbues the dam with a stark, sculptural beauty. Though aesthetics played little part in the Hume Lake Dam's original purpose, it is perhaps its most enduring legacy.

Footnotes

[1] See Edward Wegmann with Fred Noetzli, The Design and Construction of Dams, 8th edition (New York: John Wiley and Sons, 1927) for a detailed discussion of multiple arch dams and numerous illustrations of such structures throughout the world. On page VII, it is reported that "...not until 1908 when the late John S. Eastwood, a California engineer, proved in competitive bids and by actual construction the economy of building multiple arch dams that a number of structures of this type reaching in heights of upward of 250 feet have been built, both in this country and abroad." Further evidence on the proliferation of multiple arch dams prior to 1930 may be found in a listing within File No. 121-6 in the J. B. Lippincott Collection, Water Resources Center Archives (WRCA), University of California, Berkeley.

[2] The most spectacular recent example of multiple arch construction was the 703-foot high Daniel Johnson Dam (originally Manicougan Five) in Quebec, Canada, built between 1962 and 1969. See William W. Jacobus and Lilli Rathi, Manic Five: The Building of the Daniel Johnson Dam, (Garden City, New York: 1971).

[3] For more complete data on the ecology of the Southern Sierra Nevada Mountains, see Marley Brown and Michael Elling, An Historical Overview of Redwood Logging Resources within the Hume Lake Ranger District, (U. S. Forest Service Contract No. 40-9A23-0-1449, May 1981)

[4] See Brown and Elling, An Overview, pp. 53-89 for discussion of the "three phases" of logging operations in the region. Also see Hank Johnston, They Felled the Redwoods (Los Angeles: Trans Anglo Press, 1966) pp. 11-54 for discussion of early redwood logging activities.

[5] Johnston, They Felled, p. 32.

[6] Johnston, They Felled, p. 81. In 1894, Smith and Moore's Kings River Lumber Company was reorganized as "The Sanger Lumber Company." This company should not be confused with the "Sanger Lumber Company" created in 1917 when the Hume-Bennett Lumber Company changed its name.

[7] An excellent condensed history of the Hume family's involvement in the logging industry may be found in Frederick L. Honhart, "The Hackley-Hume Papers," Journal of Forest History, vol. 23 (July 1979) pp. 143. The Hackley-Hume Papers were donated to the Michigan State University Archives and Historical Collections in Lansing, Michigan, by Mrs. Jean Hume Browning in 1974 and comprised the focus of Honhart's article.

[8] Johnston, They Felled, pp. 97-99.

9 See "The Hume Lake Multiple Arch Dam," California Journal of Technology, (March 1910), vol. 15, no. 3, p. 17 for confirmation of the dam's original purpose. This article gathered various writings on the Hume Lake Dam by Eastwood and others that had appeared previously in the Journal of Electricity, Power and Gas. Also see Hackley-Hume Papers, Book 28, Thomas Hume to Ira Bennett, August 1, 1907; and George Hume to Ira Bennett, September 3, 1907, for discussions of plans to hire John B. Rogers and a "Mr. Arnold" as engineer for the Hume Lake Dam.

10 See Hackley-Hume Papers, Book 28, George Hume to Ira Bennett, September 18, 1907; George Hume to Ira Bennett, September 20, 1907; George Hume to Ira Bennett, October 9, 1907; Hume, Hefferan and Co. to William Fargo, December 19, 1907, for more on the company's deliberations concerning the Hume Lake Dam. Also see Hume Lake Dam Folder, John S. Eastwood Collection, WRCA, Berkeley, CA., John Eastwood to Hume-Bennett Lumber Co., October 1, 1907, for Eastwood's initial design proposal regarding the dam. Interestingly, at this time Eastwood conceived of the dam as consisting of "twenty 20' spans, two 30' spans and one 40' span." Exactly when Eastwood changed his design to the existing 50' span arches remains unknown, but it must have occurred before construction began in June 1908. The height of the dam was determined by the limits of the Hume-Bennett Lumber Company's land holdings along Ten Mile Creek at Long Meadows. See Johnston, They Felled, pp. 130-131, for more on the company's relationship with Gustaf Anderson, owner of 480 acres at the southwest corner of Long Meadows (which later became Hume Lake). Anderson's tract is controlled today (1983) by a religious organization that uses it as a camp/retreat. As Eastwood noted in his first letter to the Hume-Bennett Lumber Co., he proposed a storage reservoir, "...the limitations of which are to be the property lines of this company." See John S. Eastwood to Hume-Bennett Lumber Co., October 1, 1907. JSE Collection, WRCA.

11 For more on Eastwood's early life, see Charles Allen Whitney, "The Life and Times of John S. Eastwood" (unpublished manuscript; copy available at the Fresno City and County Historical Society, 1969) and Charles Allen Whiteney, "John S. Eastwood; Unsung Genius of the Drawing Board," Montana, the Magazine of Western History, 19 (Summer 1969). Also see Donald C. Jackson, "John S. Eastwood and the Mountain Dell Dam," IA: The Journal of the Society for Industrial Archeology 5 (1979).

12 Fresno Republican, July 12, 1884. At this time, it was reported that Eastwood had opened an office as "civil engineer and surveyor."

[13] Eastwood is shown posing "inside" a redwood tree at the "Smith and McCradle Millyard" in a photo dated 1884. Photo retained by the Fresno City and County Historical Society in the photo box: "Mountain Scenes: Big Trees and Others." Photo by W. R. Rodd.

[14] Fresno Republican, May 13, 1887; and Fresno Republican, Oct. 21, 1887. In the latter article, Eastwood is specifically cited as surveying a 60-mile flume for the "Moore and Smith flume." In the Fresno Expositor, Nov. 7, 1885, Eastwood is noted as being named city engineer.

[15] In "A California Flume for Transporting Lumber," Engineering News, April 11, 1891, Mr. J. M. Graham is credited as being "chief engineer" for the flume.

[16] See Whitney, "Life and Times..." for more on Eastwood's irrigation activities.

[17] For more on California early hydroelectric history, see Donald C. Jackson, "Theory and Practice in the Development of a Technological Style: California's Early 3-Phase AC Power Systems" (unpublished manuscript, presented at annual conference of the Society for the History of Technology, Oct. 1982, available from author)

[18] See Whitney "Life and Times..." for more on failure of the SJEC. Also see George Low, "The Fresno Transmission Plant," The Journal of Electricity, (April 1896), Vol. 2, No. 4, pp. 79-7-89; C. E. Dutcher, "Some Details of the Fresno Plant, " The Journal of Electricity (April 1897), Vol. 4, No. 1, pp. 1-9; and John S. Eastwood, "The Construction of Transmission Lines," The Journal of Electricity (Sept. 1897), Vol. 4, No. 6, pp. 115-117.

[19] For more on Eastwood's involvement in the Big Creek project, see David H. Redinger, The Story of Big Creek (Los Angeles, California, 1949), pp. 4-9, and Charles Allen Whitney, "Dollars and Genius Built Southern California; The Story of Henry Huntington and John S. Eastwood," unpublished manuscript (1969) on file at the Water Resources Center Archives, University of California, Berkeley. Big Creek was sold by the Pacific Light and Power Corporation to the Southern California Edison Company in 1917. Today, it supplies approximately six percent of SCEC's total power production.

[20] In discussion accompanying "The Hume Lake Multiple Arch Dam" in the California Journal of Technology, Edward Wegmann cites the ca. 1807 all-masonry Meer Allum Dam in India and the 1898 all-masonry Belabula Dam in Australia as examples of previously-built multiple arch dams. Wegmann also noted that designs for multiple arch dams had been discussed in the 1897 and 1902 Transactions of the American Society of Civil Engineers, although these dams were never actually built. Eastwood acknowledged that these previous designs were "rays of light on his patch", but he did not elaborate on exactly how he came to formulate his first multiple arch dam designs. Interestingly, he also stated that "Mr. Wegmann's citations of the examples of work embodying to a more or less degree the principle of the arch in dam construction are interesting as showing how old the first conception of merit in the arch really is (and) of the problematic value of a patent on such a device." Following construction of the Hume Lake Dam, Mr. George E. Ladshaw of Spartanburg, South Carolina, attempted to claim that Eastwood's design infringed on his patent of August 14, 1906. Eastwood vociferously objected to this allegation and, in 1912, Ladshaw's complaint was dismissed by the U. S. Circuit Court of the Southern District of California. See Hackley-Hume Papers, Bill of Complaint filed by George Ladshaw, August 16, 1911. Also see Book I, Book II and Book 32, Thomas Hume to John Eastwood, April 19, 1911; Hume-Heffern Co. to F. Cook, January 27, 1912; and Thomas Hume to George Hume, November 23, 1912, for more on this. At one time, Eastwood prepared draft descriptions of a patent for his designs but he apparently never submitted them to the U. S. Patent Office. In the latter part of his career, he actively promoted his designs by claiming there were "no royalties" for an Eastwood dam, an explicit denial of the patentability of the multiple arch concept. See Multiple Arch Dam Folder, JSE Collection, WRCA, Berkeley, and "Eastwood Bulletin," Western Engineering (March 1915), Vol. 5.

[21] As David Redinger wrote in The Story of Big Creek (p. 8) "according to Mrs. Eastwood he (John S. Eastwood) received only a small salary-just sufficient for living expenses-during the several years he spent on the preliminary work of the Big Creek project because the future seemed bright. At last he lost everything."

[22] Many writings by Eastwood on the theory of multiple arch dams can be found in the Multiple Arch Dam Folder, JSE Collection, WRCA, Berkeley.

[23] See James Leffel, Construction of Mill Dams (Springfield, Ohio, 1881). Also see J. A. Garcia-Diego. "The Chapter on Weirs in the Code of Juanelo Turriano," Technology and Culture, (April 1976), Vol. 17. pp. 217-234 for description of 16th century Spanish diversion dams with inclined upstream faces.

24 "The Hume Lake Multiple Arch Dam," California Journal of Technology. In designing the dam so that all parts ideally would be equally stressed, Eastrwood recognized that the uppermost portions of the structure would need to be thicker than water pressure would theoretically require. This was because he believed the concrete arches could not be properly constructed unless they were a minimum of 18 inches thick. Though at the top of the dam, water pressure did not necessitate the use of 18-inch thick arches, the "mechanical" requirements of construction dictated the design proportions.

25 In "The Hume Lake Multiple Arch Dam," it was reported that work on the final surveys for the dam began on June 26, 1908.

26 This is readily apparent from an analysis of photos in the "Hume Lake Dam Construction Album" retained within the Hackley-Hume Collection. This album contains more than 100 photos documenting in detail construction of the dam.

27 The caption for photo #44 in the "Hume Lake Dam Construction Album" notes that the foundation excavations "resemble rifle pits."

28 For more on Ransome and the history of reinforced concrete, see Howard Newlon, Editor, A Selection of Historic American Papers on Concrete, 1876-1926, (Detroit, Michigan: American Concrete Institute, 1976)

29 All information on the construction process is drawn from "The Hume Lake Multiple Arch Dam" or derived from analysis of the "Hume Lake Dam Construction Album."

30 "The Hume Lake Multiple Arch Dam," p. 20.

31 "The Hume Lake Multiple Arch Dam," pp. 24-26. Upon completion, the Hume Lake Dam formed a reservoir with a surface area of 87 acres and a capacity of 1,411 acre feet (or 61,500,000 cubic feet) of water. The dam contained 2,207 feet of concrete and cost $46,000. It closed an opening of 17,140 sq. ft. at a cost of $2.68 per sq. ft. A rock-fill and timber-faced dam comprised the only other type of dam given serious consideration by the Hume-Bennett Lumber Company and its cost was estimated to be $74,000. Thus, the cost of the rock fill design would have been over 68% more expensive than the multiple arch dam design. A complete breakdown of actual expenses for the dam's construction can be found in the Hackley-Hume Papers, Hume Lake Dam file. In this three page listing of expenses, entitled "Construction of Dam at Hume," it is reported that Eastwood received a total of $1,766.67 for his work on the dam, while labor costs for 1908 totaled $19,866,27. It also reports that 3,475 barrels of cement were delivered to the dam site for a total of $17,375.00 or $5.00 a barrel.

32 Johnston, They Felled. p. 105.

33 "The Hume Lake Multiple Arch Dam," pp. 19-23. Eastwood wrote that "the 24-inch gate serves as a drain gate to draw down the water in the fall in order to remove logs that may be left on the bottom of the pond at the end of the season."

34 See Johnston, They Felled, pp. 105-139, for data on the operational history of the Hume-Bennett (later Sanger) Lumber Company.

35 See ca. 1934 "Report on Power Value of Hume Lake Project on Ten Mile Creek, Sequoia National Forest, California" by E. Logan, Senior Hydroelectric Engineer, U. S. Forest Service, San Francisco, California, for more on this subject. A copy of this report is in the files of the Sequoia National Forest and was brought to the attention of the author by Mr. Clay Brandow, hydrologist for the U. S. Forest Service. Interestingly, it appears that the Hume interests also explored the possibility of using the dam for hydroelectric power generation in the 1920s, but nothing ever came of it. See Hackley-Hume Papers, Book 9, page 607, George A. Hume to R. W. Hefferan.

36 In the early 1940s, the Forest Service undertook some minor remedial work on the upstream face of the dam. Photographs and studies related to this work can be found in the Hume Lake Dam folder in the Walter L. Huber Collection, WRCA, Berkeley. For complete documentation of the California Dam Safety Division's involvement with the Hume Lake Dam, see "Hume Lake Dam-File #692," Dam Safety Division, Department of Water Resources, Sacramento, California. This file indicates that in 1954 the dam was "leased" to the State of California by the Forest Service so that state funds could be expended on its repair. In an agreement signed on December 1, 1953, by Harry Anderson, Administrative Officer for the California Department of Fish and Game, and L. M. Carrell, Acting Regional Forester for the Forest Service, this lease was stipulated to last for 20 years. However, in 1960 the lease was terminated and the dam reverted to Forest Service control.

37 The following are Eastwood's known dams, with construction dates:

1. Hume Lake Dam, California, 1908-09
2. Big Bear Valley Dam, California, 1910-11
3. Big Meadows Dam, California (only partially built and never completed), 1911-12
4. Los Verjeles Dam, California, 1913-14

5. Kennedy Dam, California, 1914
6. Argonaut Dam, California, 1916
7. Mountain Dell Dam, Utah, 1916-17 (completed 1925)
8. Eagles Nest Dam, California, 1917
9. Murray Dam, California, 1917
10. San Dieguito Dam, California, 1917
11. Malad Dam, Idaho, 1917
12. Lake Hodges Dam, California, 1917-18
13. Cave Creek Dam, Arizona, 1922-23
14. Fish Creek Dam, Idaho, 1919-20
15. Anyox Dam, British Columbia, 1922-23
16. Weber Creek Dam, California, 1922-23
17. Little Rock Dam, California, 1922-24

Eastwood died on August 12, 1924, while surveying near his ranch on the Kings River. He entered the river to save a woman who had been swept into the current and he apparently died of a heart attack while in the water. The location of his death is now inundated by the Pine Flat Reservoir.

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Hume Lake Dam

All photographs are by Dick Freer, National Park Service Western Regional Office Photographer, August 1982.

CA-16-1 General view of dam looking upstream (south from "Dryer Hill."). Site of former sawmill is at right.

CA-16-2 General view of dam looking upstream (south).

CA-16-3 View looking upstream with dam in background and bolts associated
with former timber flume in foreground.

CA-16-4 View looking upstream and slightly west showing center section of dam.

CA-16-5 View looking upstream and slightly east showing center section of dam (buttresses #6, 7, 8).

CA-16-6 View looking upstream and slightly west showing center section of dam (buttresses #4, 5, 6, 7)

CA-16-7 View looking upstream and to the east showing buttresses #10 and #11.

CA-16-8 View looking upstream and to the west showing buttresses $8, #9, and #10.

CA-16-9 Detail view looking upstream at the deepest section of the dam (buttresses #7 and #8).

CA-16-10 Detail view of buttress #8 looking east. The impressions of wooden forms are visible on the concrete.

CA-16-11 Detail view of buttress #8 and half of arch #7 showing the upstream inclination of the arch. Also visible is a former waste-gate in the arch that is now filled with concrete.

CA-16-12 Detail view of buttress #8 and half of arch #7. The impressions of the wooden forms are visible on the concrete. Also visible is the placement of the dam directly on the bedrock.

CA-16-13 Detail view of buttress #4 showing the results of poor construction work. Though not a serious structural deficiency, the "honeycomb" texture of the concrete surface was the result of inadequate tamping at the time of the initial "pour."

CA-16-14 Detail view of buttress #4 showing the results of inadequate tamping. The size of granite aggregate used in the dam's concrete is clearly shown.

CA-16-15 Detail view of sawmill powerhouse foundation (constructed in 1909) showing the wire-rope and railroad rails used as reinforcement in the concrete. This same mode of reinforcement was used in the dam.

CA-16-16 Detail view of powerhouse foundation showing wire-rope reinforcement in the concrete.

CA-16-17 Detail view of original 12" outlet valve between buttresses # and # .

CA-16-18 General view of upstream side of dam looking west.

CA-16-19 Detail view of upstream side of dam looking west. The reinforced concrete copyings on top of the arches were added in the 1950s.

CA-16-20 General view looking north towards dam from across the reservoir.

CA-16-21 General view of reservoir looking south.

CA-16-22 Photocopy of circa 1920 photographs of John S. Eastwood. Reproduced courtesy of Charles Allen Whitney, Santa Monica, CA.